

A large, stylized graphic on the left side of the slide depicts a globe with latitude and longitude lines. A white jet aircraft is shown flying across the sky, leaving a long, bright white contrail that extends from the top left towards the center of the slide.

# **Effectiveness of the Automatic Dependent Surveillance – Broadcast (ADS-B) Ground Based Transceiver (GBT) Parrot System in Alaska**

**2004 ICNS Conference**

**April 26-30, 2004**

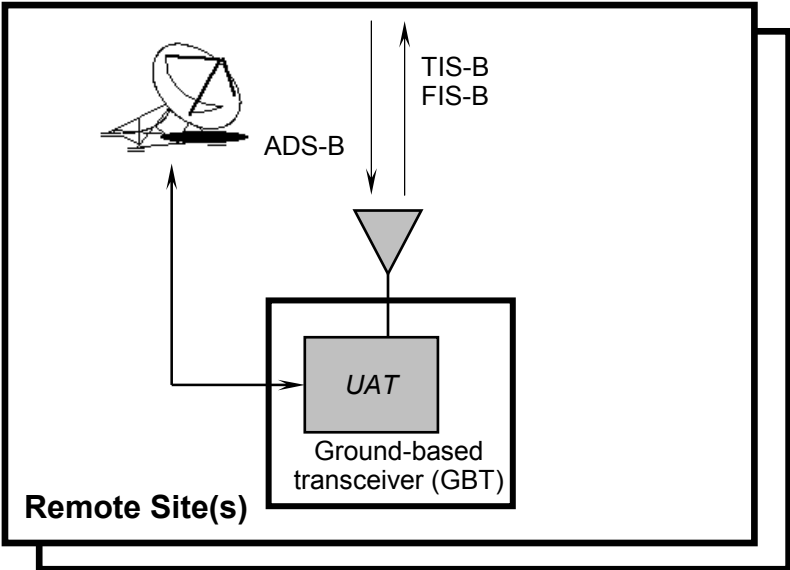
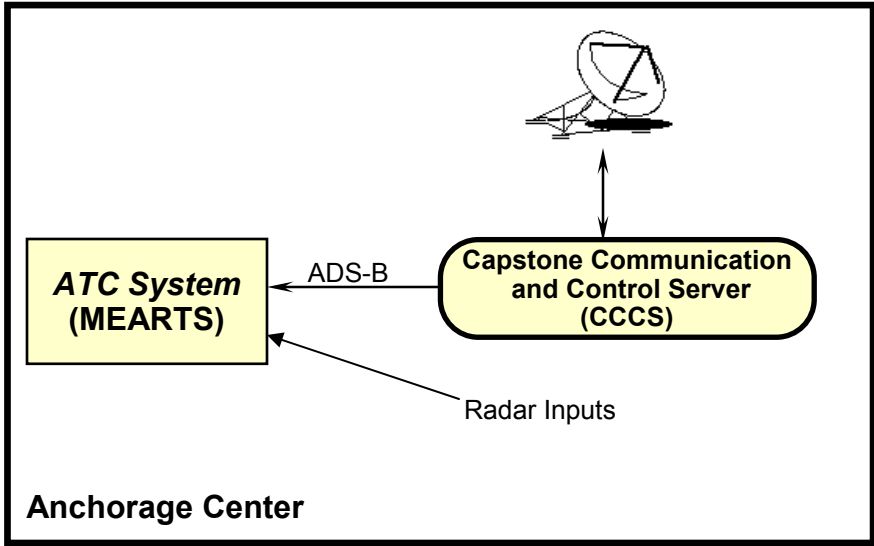
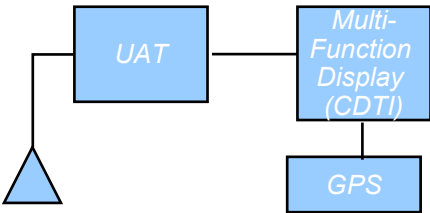
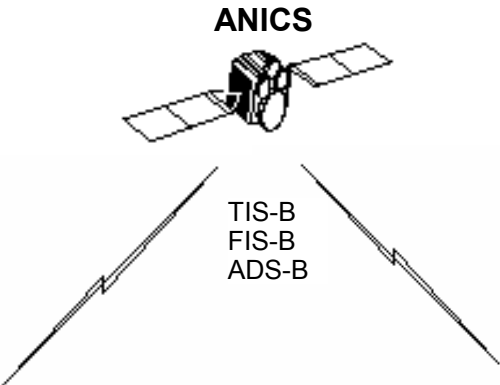
**Dr. Young C. Lee, Chris Moody, and James Reagan  
MITRE/CAASD**

# Background

---

- **Air Traffic Control (ATC) “Radar-Like Services” were approved for operational use in Bethel, AK area January 2001**
  - **ATC surveillance via Global Positioning System (GPS)/ADS-B**
  - **Uses five nautical mile (NM) separation standard**
  - **One of Capstone’s major initiatives and accomplishments**
- **Allows GBTs to perform ATC function equivalent to secondary surveillance radar/transponder**
- **Ten GBT sites now installed in Southwest AK**
  - **All sites supported by Anchorage Center**
  - **Microprocessor En Route Automated Terminal System (MEARTS) is the automation system**
  - **Three GBT sites are currently operational**
- **200 aircraft equipped with ADS-B**
  - **Near 100% equipage in Bethel, AK area**

# Capstone Architecture



# Integrity Monitoring for Radar-Like Services (RLS)

---

- **Some form of integrity monitoring of GPS/ADS-B is required for the Capstone “Radar-Like Services” application**
- **ADS-B messages include fields for avionics self-reporting of the integrity of ADS-B position information**
- **ADS-B surveillance system can rely on the transmitter to perform self-reporting**
  - **Through integrity monitoring performed within the onboard GPS receiver (via Receiver Autonomous Integrity Monitoring (RAIM), or Wide/Local Area Augmentation Systems (WAAS/LAAS))**
- **RLS showed difficulties prior to commissioning**
  - **Too many false alarms**

# Integrity Monitoring for RLS (concluded)

---

- **To expedite RLS commissioning, team decided to monitor GPS integrity through a “parrot” system established as part of the GBT**
- **The GPS sensor within the GBT reports its position in “fixed ADS-B beacon” transmissions**
- **Transmissions are received by the redundant GBT and forwarded to MEARTS**
- **MEARTS compares the reported position to the survey and provides an integrity alarm if out of tolerance**

# Objective of Our Analysis

---

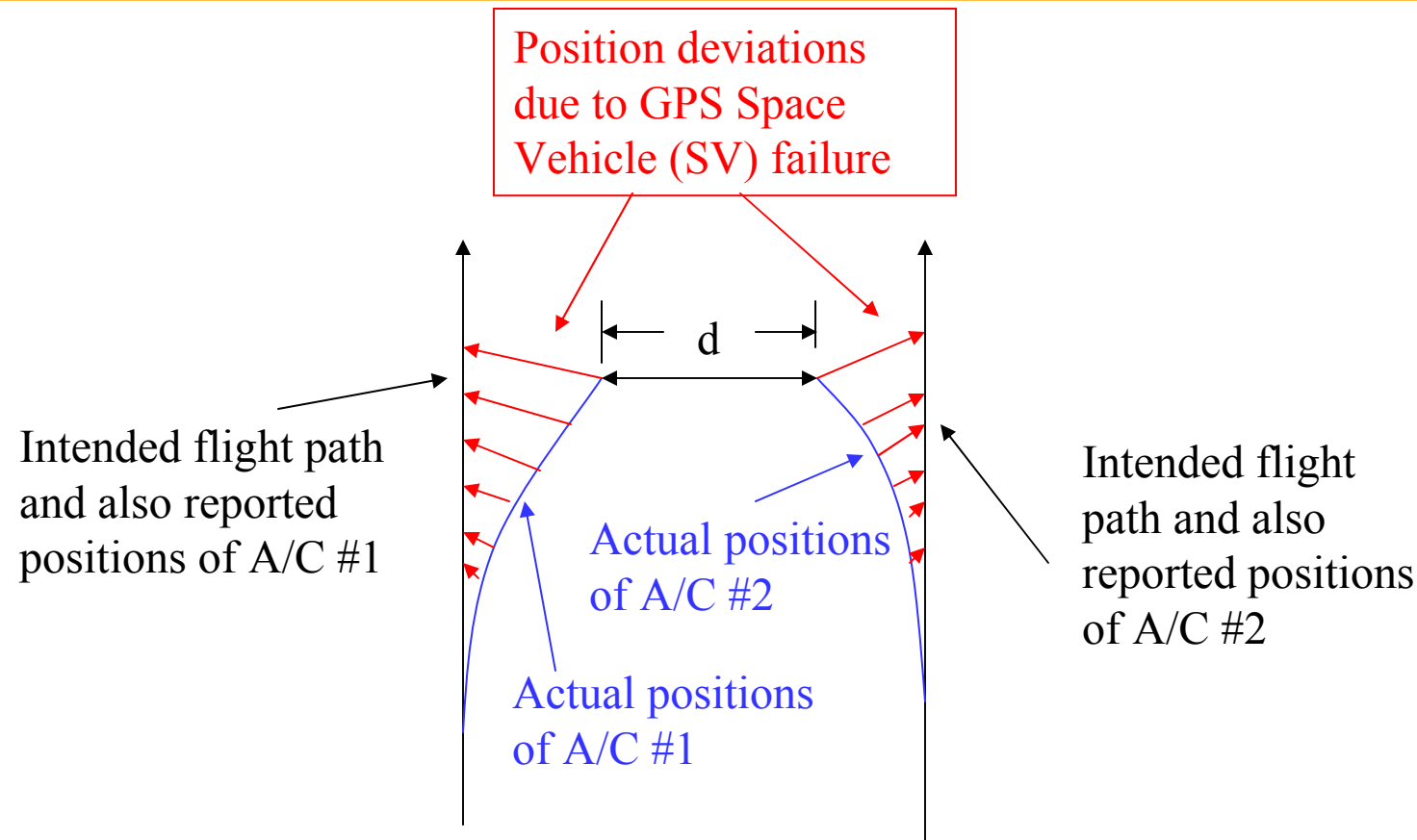
- **Parrot system is not a total answer for integrity monitoring of GPS satellites**
  - Aircraft may see slightly different set of satellites than the GBT
  - GBT monitor may see the failed satellite but due to differences in satellite selections and geometry, failure could have greater error impact on aircraft than on monitor
- **Question: How effective is the parrot system at detecting failures of GPS satellites?**

# Problem Formulation

---

- **Hazardously Misleading Information (HMI) event satisfies three conditions simultaneously**
  - **A GPS integrity failure occurs**
  - **Failure results in a range error large enough to cause an unacceptably large position error for the user such that:**
    - **Two aircraft approach each other beyond a certain minimum separation distance without ATC's (or pilot's) awareness**
    - **Minimum separation distance violated is defined as being  $(5-\Delta)$  NM, where  $\Delta$  is a small fraction of 5**
      - **With selection of  $\Delta = 0.5$ , minimum separation distance = 4.5 NM**
  - **The parrot system fails to detect the above event**

# HMI Event – Example



HMI occurs when  $d \leq (5 - \Delta)$  but reported position separation  $> 5$  NM and no parrot alarm



# Analysis Approach

---

- **$E\{\text{Number of HMI events per year}\}$   
 $= \Pr\{\beta\} E\{\alpha \mid \beta\}$  where**
  - $\alpha$ : Number of HMI events per year
  - $\beta$ : Satellite failure with a ranging error large enough to cause HMI
- **$\Pr\{\beta\}$  based on satellite failure rates from two different sources**
  - 3 times per year per constellation (GPS Standard Positioning Service (SPS) Performance Standard)
  - 3 failures over the last 10 years (observed data)
- **$E\{\alpha \mid \beta\}$  evaluated via simulation**

# ADS-B GPS Receivers Characteristics

---

- **The GPS receivers used by aircraft and GBT parrot systems have identical characteristics**
  - **Certified according to the Technical Standard Order (TSO)-C129**
    - **Integrity of GPS signals is monitored by Receiver Autonomous Integrity Monitoring (RAIM)**
  - **Elevation mask angle fixed at 7.5 deg**
  - **Tracks up to eight satellites simultaneously**
  - **Satellites selected with hysteresis**
    - **Will not switch to a new set unless Position Dilution of Precision (PDOP) improves by 0.4 or larger**
    - **Two receivers at the same location may track different sets of satellites depending on when they were initialized**

# Two Issues with the Current Monitoring Scheme by the Ground Monitors

---

- **Not all satellites being used by various users are monitored by the GBT parrot systems**
  - Geographic decorrelation
  - Hysteresis
  - Terrain blockage (not modeled)
- **Even if all satellites used by the user are monitored by the GBT parrot systems, the monitoring in position domain may not be perfect**
  - A ranging error on the failed satellite causes different position error magnitudes between the monitor and the user in general
  - A tight parrot alarm threshold rarely causes an HMI event

# Conditions for the Simulation Model

---

- **GBT locations**
- **Satellite selection logic based on PDOP with hysteresis**
- **Constellation: 28 satellite orbital positions (as of 08/03/03)**
- **User traffic coverage area**
  - **Areas with radii of 100, 200, and 300 NM from Bethel**
  - **Candidate user locations represented by grid points with 2.5-NM spacing**
- **Stabilization and evaluation periods for the monitors and the users**

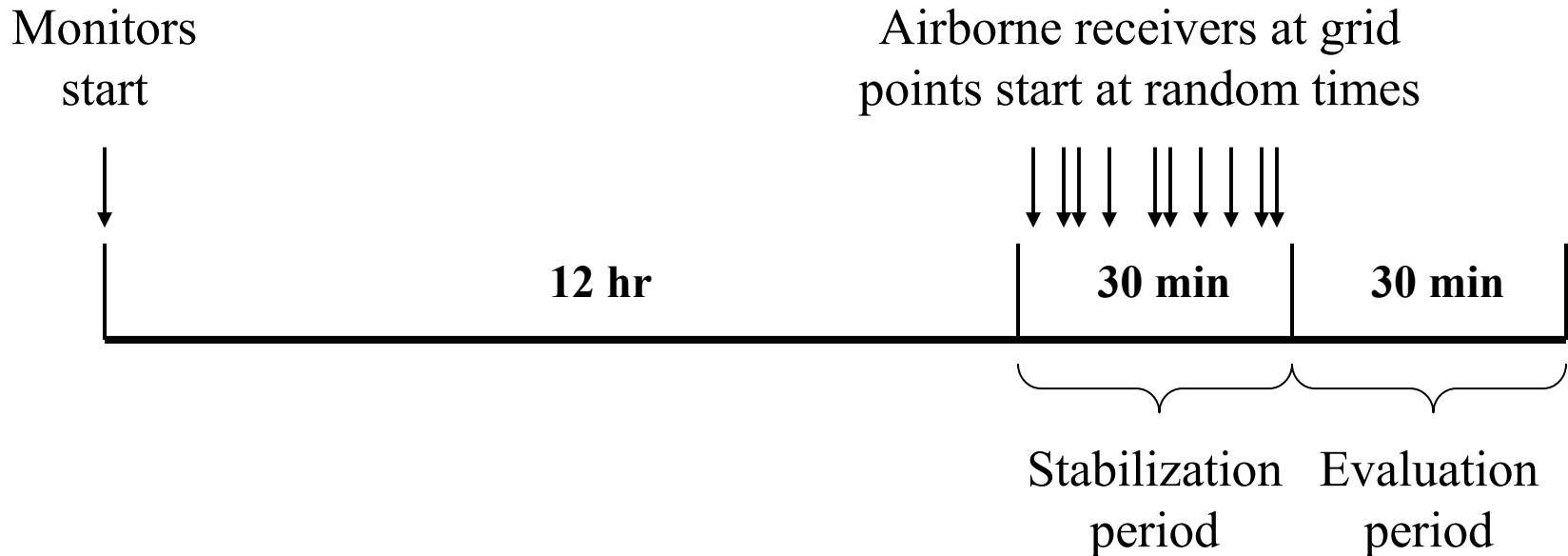
# Monitor Locations: Three-Monitor Configuration



# Monitor Locations: Ten-Monitor Configuration

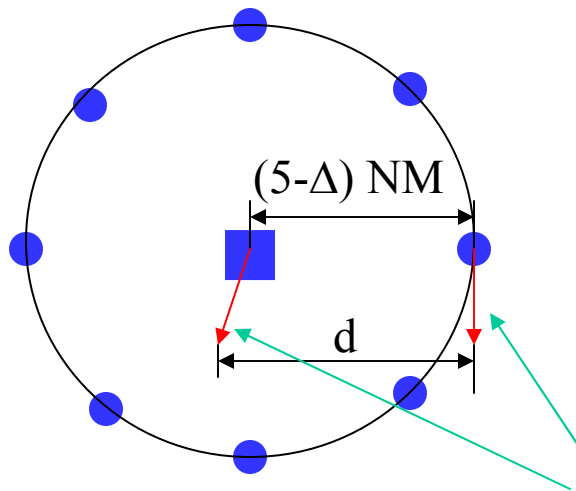


# Simulation Runs (3 of 3)



- **The entire timeline is shifted by 30 minutes for each simulation run**
- **The final result is derived by averaging the 48 runs of one day**

# Grid Point (Selected User Location) and Vicinity Points (Adjacent User Location)



For each grid cell, eight vicinity cells are considered

Each pair of grid cell and vicinity cell is examined

$d$ : reported separation

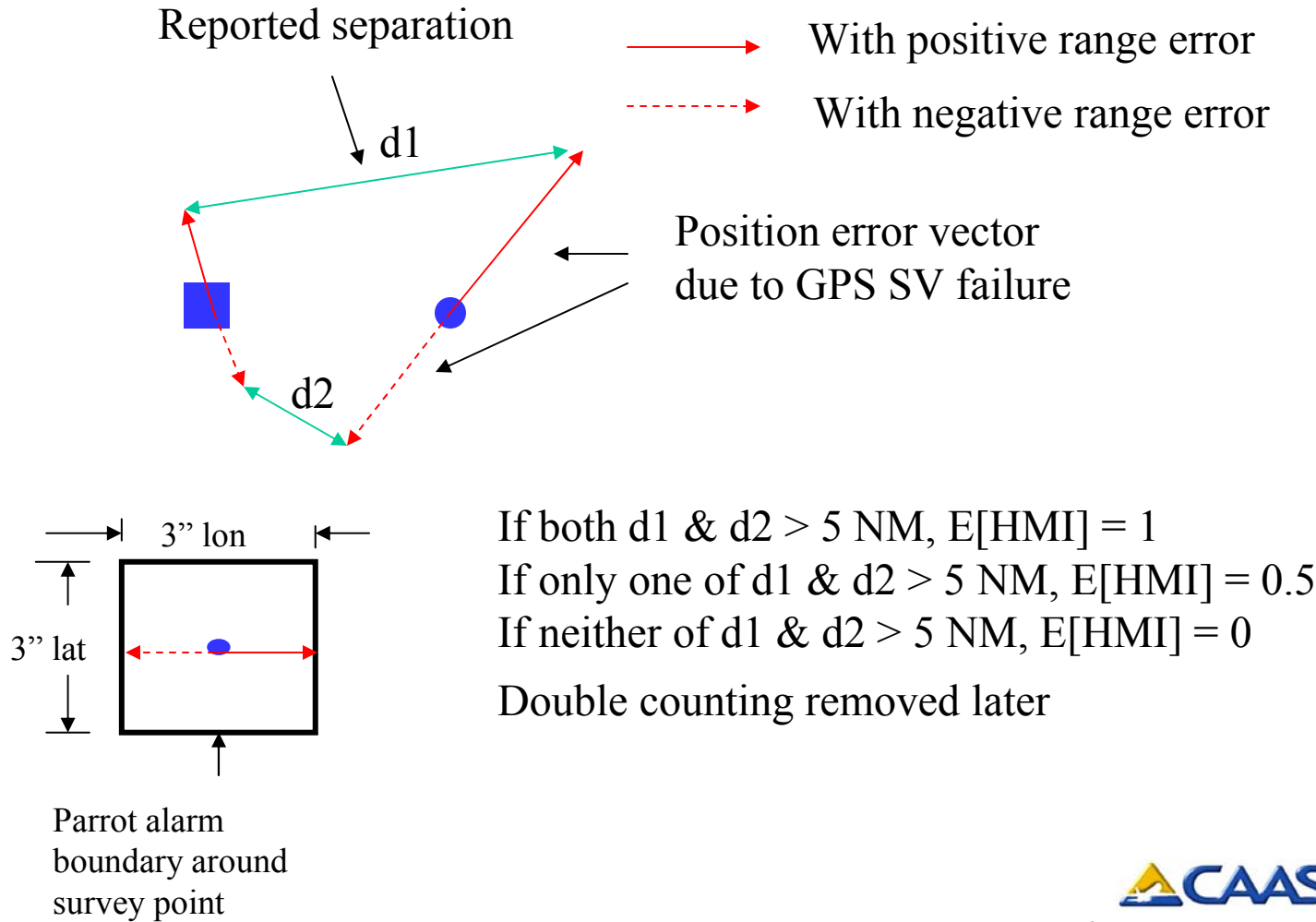
Position error due to GPS SV failure

HMI results if  $d > 5$  NM

$d$  is evaluated for every pair of grid/vicinity pair and for failure of each satellite selected by the aircraft at the grid cell



# Satellite Monitored by GBT and Selected at Both Grid and Vicinity Points

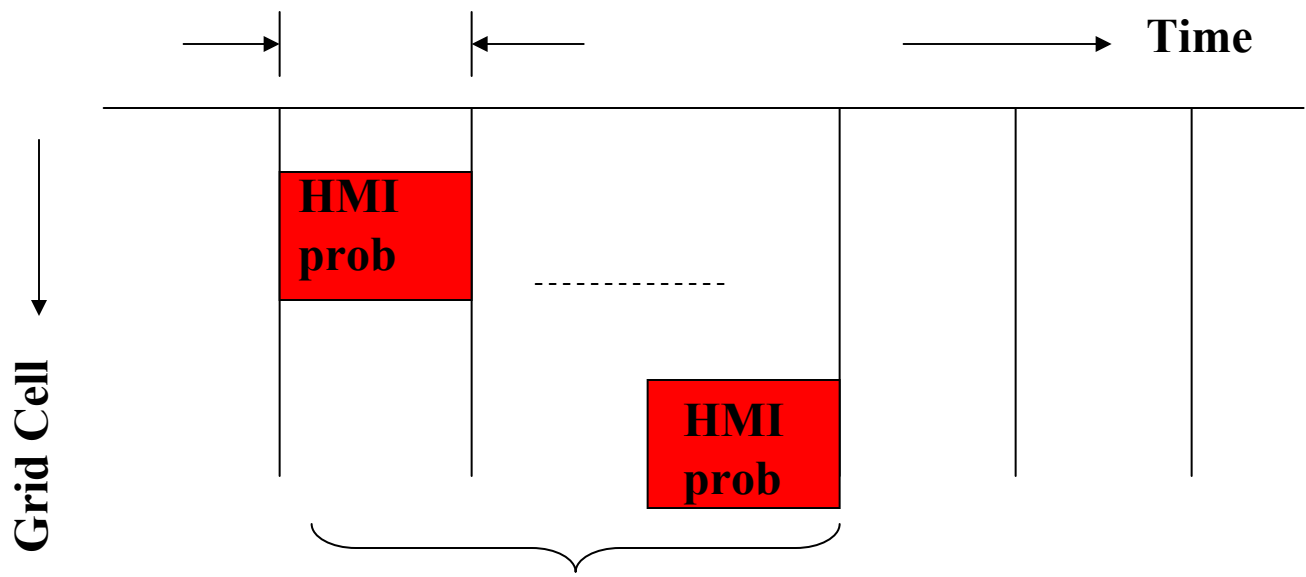


# E {Number of HMI Events / Yr / Space-Time Point}

Number of Monitors	Based on SPS Performance Std. Radius from Bethel, AK			Based on Historical Data Radius from Bethel, AK		
	100 NM	200 NM	300 NM	100 NM	200 NM	300 NM
0 monitors (w/o Parrot)	0.0768	0.0758	0.0742	0.00768	0.00758	0.00742
3 monitors	0.00701	0.00783	0.00893	0.000701	0.000783	0.000893
10 monitors	0.00130	0.00158	0.00226	0.000130	0.000158	0.000226
Mask angle = 7.5 deg, 28 SVs Stabilization and evaluation times = 30 min						

# Accounting for Duration of Integrity Failure Event

Average time between arrival of successive pairs of exposed aircraft (e.g., 10 min)



Duration from the time a satellite integrity failure that may cause HMI occurs until the failure is reported to ATC (1 hr)

# Accounting for the “Operational Exposure” to HMI

---

- **$E\{\text{HMI events anywhere in the region per year}\}$   
 $= N * E\{\text{HMI events per year per space-time point}\}$   
where  $N = N1 * (N2/N3)$** 
  - **N1: Expected number of locations within the region with traffic pairs flying in close proximity at the same altitude at any given time**  
**For example, we may assume\***
    - 2 for 100 NM radius
    - 3 for 200 NM radius
    - 4 for 300 NM radius
  - **N2: Duration from the time a satellite integrity failure that may cause HMI occurs until the failure is reported to ATC (e.g., 1 hr)**
  - **N3: Average time between arrival of proximate traffic pairs (e.g., 10 min)**

**\* It is considered that the traffic outside 100 NM radius is less dense.**

# E {Number of Years Between HMI Events Over the Given Coverage Region}

---

Number of Monitors	Based on SPS Performance Std. Radius from Bethel, AK			Based on Historical Data Radius from Bethel, AK		
	100 NM	200 NM	300 NM	100 NM	200 NM	300 NM
0 monitors (w/o Parrot)	1.1 years	0.7 years	0.6 years	11 years	7 years	6 years
3 monitors	11.9 years	7.1 years	4.7 years	119 years	71 years	47 years
10 monitors	64.1 years	35.2 years	18.4 years	641 years	352 years	184 years
Mask angle = 7.5 deg, 28 SVs Stabilization and evaluation times = 30 min						

# Analysis Conclusions

---

- **Using the results corresponding to three monitors and “historical” GPS satellite failure data likely yields the most realistic event expectations**
  - Operations at “risk” every 47 to 119 years
- **Current operations appear to be safe considering**
  - RLS began in Alaska in 2002
  - Capstone equipped aircraft scheduled to receive an avionics upgrade to include a GPS/WAAS receiver, likely to negate the problem
  - HMI alone does not constitute an aircraft collision
    - Satellite failure causing HMI would have been detected quickly as a RAIM alarm

# Recommendations

---

- **Verify the traffic density assumptions in and around the Bethel airport**
- **Activate and commission the seven inactive GBTs as “parrots” as soon as possible**
- **Investigate the cost and performance of more effective monitoring approaches, including**
  - **Testing new avionics as soon as available**
  - **Providing a monitor and alarm function for RLS activities at Bethel**
  - **Using a better reference receiver**
- **Consider limiting expansion of Instrument Flight Rules (IFR) operations in Alaska until new generation avionics and/or a WAAS monitoring function are in place**